

[Go to Home Page](#)

The Slowing Spin of Earth

*Is Earth's Rotation Slowing
Down Throughout Time?*



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A-Quest-For-Creation-Answers

The Earth-Moon

From the essential perspective that the Earth-Moon could represent an interrelated system, the respective spin-orbital movements should be evaluated to predict the effect of any changes that might result with the passage of time. The spin-orbital rates can be predicted to ultimately change with time due to the spin rate of the Earth. Modern research shows that the spin of the Earth has slowed by a fractional amount

throughout the prior 4,000 years. In association with the slowing rotation of the Earth is the slowing period of the Moon. It appears that the orbit of the Moon is ever growing wider--and thus the period of the Moon is simultaneously lengthed.

Subsequent paragraphs and sections will then attempt to make it clear that even though small spin-orbital variations do occur, the Earth-Moon appears to generate time cycles that have very long-term average definitions.

Modern records

The service of monitoring the rotation of the Earth is performed by the International Earth Rotation Service (IERS).

The following quote--borrowed from IERS--manifests a small amount of variation in Earth's rotation:

"Universal time and length of day [LOD] are subject to variations due to the zonal tides (smaller than 2.5 ms in absolute value), to oceanic tides (smaller than 0.03 ms in absolute value), to atmospheric circulation, to internal effects and to transfer of angular momentum to the Moon orbital motion."

Modern monitoring then indicates that Earth's rotational rate frequently varies in magnitude by a few milliseconds. Even though the magnitude of the variation appears to be extremely small, it is nevertheless manifest that Earth's rotational rate does vary by a tiny amount from season-to-season and from year-to-year.

To help illustrate that Earth's rotation does tend to vary--even throughout centuries of time--a catalog of the duration of previous days is tabled in Appendix A. (Note the catalog was borrowed from the IERS. The catalog largely represents a compilation of data provided by L.V. Morrison, Royal Greenwich Observatory).

It should be very clear from Appendix A that the rate of Earth's rotation both increases and decreases across rather lengthy stretches of time. For example, observations are tabled for some 374 years (from 1623 CE to 1997 CE). Throughout the many years covered in this table, it is apparent that the length of the solar-day was a fraction of a second faster than 86,400 seconds about 41 percent of the time. It is equally apparent that the length of the solar-day was a fraction of a second slower than 86,400 seconds about 59 percent of the time.

Due to the magnitude and frequency of the cited variations in Earth's rotation--across a time span of 4 centuries--it would not be possible to conclude that Earth's rotation is slowing down according to a long-term trend.

In order to identify a trend in the rotation of the Earth, it is necessary to try and look further into the past (or across a time-span longer than but a few centuries).

The length of the solar day (LOD) is defined to be 24 hours long (or also 86,000 seconds in length). In the last half of the Twentieth Century, the length of the solar day was very accurately measured for the first time using atomic clocks. These very accurate measurements show an increase in the length of the day of 0.0017 seconds (or 1.7 milliseconds) for the century. It is here significant that these measurements additionally show Earth's rotation is changing at a variable rate. Essentially, the measurements do not reflect that Earth's rotation changes at any constant rate.

A slowing trend

On the basis of Earth-Moon alignments at the time of ancient eclipses, it is possible to conclude that--as a trend--Earth's rotation may be slowing down.

From recorded eclipses, modern researchers have been able to determine that the length of the day in ancient times was a bit shorter than the length of the modern day (86,400 seconds).

To illustrate more of how this conclusion is arrived at, suppose by way of an hypothetical example that a solar eclipse was recorded at Babylon 812,345 days ago. The recorded eclipse on that day is significant because of the passing of the Moon's shadow over that location (Babylonian). If each and every day from then to now traversed no more or less than 86,400 seconds then the shadow of the hypothetical eclipse should have passed at a location 64 degrees in longitude further away from Babylon. Because the shadow instead was observed to pass over Babylon, it can be concluded that the length of the previous day was a bit faster. In essence, a longitudinal shift of 64 degrees in 812,345 rotations is inherently equal to an average increase in the length of the day equivalent to 1.7 milliseconds per century.

Note from the hypothetical example of an ancient eclipse at Babylon that 36524 solar days occur in each passing century. It then follows that an increase in the length of the day equivalent to 1.7 milliseconds per century would result in a time shift of 62.09 seconds for the century (where 0.0017 spin seconds per century times 36524 solar days is equal to about 62.09 spin seconds of time change for the century). Because a time increase of 62.09 spin seconds (or 931.35 arcseconds of longitude) is predicted on a per century basis then a total time shift of 15,356 spin seconds (or a longitudinal shift of 230,340 arcseconds, or 64 degrees) would accrue in 812,345 solar days or in 22.24 centuries (where 62.09 seconds of change per century times the square of 22.24 centuries when divided by 2 is equal to about 15,356 spin seconds) .

Because a number of ancient eclipses are on record, then changes in the rate of Earth's rotation can be predicted throughout a number of centuries of years into the past. On the basis of these records, modern physicists and astronomers have identified the cited slow-down trend in the rotation of the Earth. (For additional information about research of eclipse records, refer to Appendix C).

The following diagram--which is based upon interpretations espoused in Appendix C--attempts to illustrate the cumulative change in Earth's rotation over the previous four-thousand years:

INDICATED INCREASE IN THE LENGTH OF THE DAY
(As Estimated from Ancient Eclipses)

Time Range	Spin Rate Shift	Increase in Day
4000 years	- .0018 sec/cen.	+ .07 seconds

The diagram shows that throughout the previous 4,000 years the length of the day has gradually grown longer (where the ever increasing length of the day can be attributed to the slowing rotation of the Earth). The indicated increase in the length of the day (a spin rate change of - 0.0018 seconds/century) across 4,000 years is shown to ultimately accrue to a total increase of + 0.07 seconds.

Ancient eclipse records then ultimately indicate that the rate of Earth's rotation has slowed down throughout previous millennia. A trend is then indicated in that from 2000 BCE to 2000 CE (or for a time-span of 4,000 years) the length of the modern day appears to have increased by a surplus of + 0.07 seconds from the length of the ancient day.

The cited increase of + 0.07 seconds from the length of the ancient day at 4,000 years ago means that the spin rate of the Earth has slowed at a rate of 0.0018 seconds per century--as diagrammed).

The indication that the length of the day has increased by a total amount of 0.07 seconds throughout the prior 4,000 years seems tiny or insignificant. This time-span represents only a fraction of one second (a time-stretch that is less than the length of a heartbeat... or shorter than a handclap). The difference of .07 seconds does--however--have significance in that the effects of a slowing rotation are cumulative and the resulting longitudinal change becomes large across thousands of years of time. For additional information concerning the cumulative effects of the slowing spin of the Earth, refer to:

A Case for Created Time?

Another perspective that can be focused from the cited slowing trend is that--even though Earth's rotation is experiencing a slowing trend--the magnitude of the change is very small. It seems that modern measurements and ancient eclipse records alike indicate that the length of the day in the past, as well as the length of the day in the modern era, completes in about the same relative amount of time (86,400 seconds). The indicated increase (a total of .07 seconds in 4,000 years) then tends to reflect a

rotating Earth that is remarkably stable. On a scale of the prior 4,000 years, the tiny magnitude of Earth's rotational slow-down tends to prove that the Earth has continued to spin at a functional rate. Essentially, the length of the day is proven to remain adequately uniform--even across thousands of years.

Yet another indication that as a trend the rotation of the Earth is slowing comes from coral fossil records. Because living coral records growth markers like tree rings then the record of the growth rings can ultimately be correlated to the seasonal progression.

Based upon interpretations espoused by leading researchers in this field, it is widely believed that the annual cycle of the ancient past contained more days than the current annual cycle (which is 365.24). The indication that the ancient year contained more days is interpreted to mean that the spin of the Earth has gradually slowed across millions of years. Based upon estimations concerning the number of millions of years in the past when certain fossil specimens once lived, it is believed that the rotation of the Earth has slowed by an average amount of 0.001 to 0.002 seconds per century.

CHANGE IN THE LENGTH OF THE DAY (from 24 Million Years)		
Time Range	Spin Rate Shift	Day Increase
24 million yrs	-.0015 secs/cent	+6.0 minutes

Part of the problem in correlating coral fossils to the rate of the presumed slowing of the Earth is that the rotation rate appears to change very slowly. Because an average increase in the length of the day is interpreted to be about 0.01 to 0.02 seconds per millennium, it isn't possible to specifically correlate the seasonal passage to such a tiny amount of rotational change (only 1 or 2 milliseconds per century).

For example, at the tiny change of 0.01 to 0.02 seconds per millennium, it would require the passage of from 12 to 24 million years before even a single extra day per year would show up in the cited coral records.

This means that a great amount of time (many millions of years) would ultimately be required before a change of only a single day of difference could be counted (or ultimately even be noticed) amid the seasonal growth rings.

It is then the passage of so great an amount of time required to detect any change in the seasonal progression that thwarts the interpretation of coral fossils. The choice of

using coral fossils to detect a change in the number of days across the seasons inherently requires the passage of upwards of a hundred million years to begin to notice a one or two percent change in the day count of the ancient annual cycle.

A problem then is that counting coral fossils can't define changes in Earth's rotation in a time-range anywhere close to the modern era. Only on a time-scale of about 50 or 60 million years does the record of ancient coral fossils begin to indicate that the definition of the solar year might have been a bit different from 365 or 366 days. The definition of a definitive change in the day count of the ancient solar year thus requires the detection of coral fossils containing appreciably more growth rings from hundreds of millions of years into the past. On this basis, it can be assumed that Earth's rotational rate was once faster, and it further can be assumed that the rotational rate has gradually slowed-down throughout the intervening hundreds of millions of years.

As is further explained in subsequent sections, the lunar-month cycle (or the synodic month) does happen to complete at a much faster rate than the solar year (over 12 times as fast). This tends to mean that the fossil record relative to the Moon can more effectively be used to identify prior changes in the configuration of the Earth-Moon. Essentially, it is considerably more straightforward to interpret 29 or 30 growth markers in correspondence with the passage of the lunar month than to try and interpret 365 or more growth markers in correspondence with the passage of the solar year. Furthermore it is easier to detect changes in the prior lunar-month cycle from bivalve mollusk fossils that may have lived only 5 or 10 million years ago than it is to detect changes in the prior solar year from coral fossils that may have lived over 100 million years ago.

What about the orbit of the Moon?

The interpretation that Earth's rotation is slowing down appears to be good for explaining the phenomenon of a longitudinal shift at the time of ancient eclipses (as previously explained). The interpretation of a slowing rotation of the Earth can however be faulted in the regard that--while during an eclipse a longitudinal position can roughly be determined--any associated orbital variation of the Moon has to ultimately be estimated.

The modern lunar-month cycle (or the synodic month) has been determined to be 29.53059 days (on the average). If it is assumed that the rotation of the Earth has slowed relative to the Sun by the average rate of 0.01 seconds per millennium, and if it is further assumed that the rotation of the Earth has also slowed relative to the Moon by the average rate of 0.01 seconds per millennium, then--by way of example--it can be concluded that the count of the synodic month of 6,500 years ago was 29.53062 days, or 1.92 spin-seconds faster than the modern rate. (Note that each lunar month contains 29.53 rotations of the Earth and if the rotational rate of the Earth is assumed to slow-down by 0.01 seconds per millennium then the corresponding count of the lunar month can be predicted to become reduced at the rate of 0.2953 spin-seconds per millennium). If--on the other hand--it is assumed that the rotation of the Earth has not

slowed relative to the Moon, then the definition of the synodic month of the past would be unchanged from the modern rate.

The length of the ancient lunar month is then difficult to exactly determine as it is assumed that the Moon in it's orbit experiences an acceleration effect due to Earth's spin. This essentially means that--while the modern definition of the synodic month is equal to 29.53059 days--the definition of the ancient synodic month is not as clear.

Like a ball attached to an ever lengthening string, the Moon--which moves at a much slower rate than the rotating Earth--is interpreted to experience a commensurate acceleration effect due to Earth tides. As a consequence of the more rapidly spinning Earth and the action of gravity, the spinning Earth is then slowed down and simultaneously the Moon is accelerated. Because the Moon is being accelerated in it's orbit, it's distance from the Earth is indicated to increase. Then, as the Moon moves farther from the Earth, more time is ultimately required for the Moon to complete an orbit.

Measurements made over the prior 30 years indicate the Moon's orbit is moving away from the Earth at the rate of 4 centimeters or 1.5 inches per year. Note that an increase of 1.5 inches per year--if constant throughout time--would accrue to 500 feet in a time-span of four-thousand years. (For additional information refer to: http://www.physics.uc.edu/~sitko/Fall2000/9-TP_part2/tp2.html).

The rotation of the Earth is then believed to slow down, and the Moon which travels in the same eastward direction as Earth's rotation is believed to simultaneously move away into a wider orbit.

The definition of the ancient synodic month

With the spin of the Earth ever slowing-down and with the Moon ever moving into a more distant orbit, it can be discovered that the definition of the synodic month (at about 29.5 days) appears to have remained unchanged for many thousands of years.

Of significance here is that growth records in ancient bivalve mollusk shells have been used by modern researchers to ultimately estimate the length of the synodic month in the more distant past.

The following table attempts to show trends in the definition of the ancient synodic month--based upon interpretations espoused by Berry and Barker (1), and Pannella (2):

DAYS IN THE ANCIENT SYNODIC MONTH
(Based Upon Bivalve Fossil Data)

1. = experimental value, interpreted as (days/month), (Berry and Barker 1975)
 2. = experimental value, interpreted as (days/month), (Pannella 1972 and Thompson 1968).
-

PLEISTOCENE FOSSILS
(-11,000 to -1,800,000 Years)

- | | |
|---------------|--------------------------------------|
| 1 = 29.5 Days | Sandstone
Punta Cholla Sonora |
| 1 = 29.5 Days | Palos Verdes Formation
California |
| 1 = 29.6 Days | San Pedro Sandstone
California |
| 2 = 29.1 Days | YPM-IP-26310 |
| 2 = 29.6 Days | YPM-IP-26307 |
| 2 = 29.0 Days | YPM-IP-26305 |
| 2 = 29.3 Days | YPM-IP-26312 |
| 2 = 29.2 Days | YPM-IP-26309 |
| 2 = 29.1 Days | YPM-IP-26304 |
| 2 = 29.4 Days | YPM-IP-28493 |

PLIOCENE FOSSILS
(-1,800,000 to -5,000,000 Years)

- | | |
|---------------|-------------------------------------|
| 1 = 29.6 Days | Caloosahatchee Formation
Florida |
| 1 = 29.7 Days | Caloosahatchee Formation
Florida |

MIOCENE FOSSILS
(-5,000,000 to -23,000,000 Years)

- | | |
|---------------|--------------|
| 2 = 29.7 Days | YPM-IP-28494 |
| 2 = 29.4 Days | YPM-IP-26376 |
| 2 = 29.8 Days | YPM-IP-28495 |
| 2 = 29.4 Days | YPM-IP-28483 |
| 2 = 29.4 Days | YPM-IP-26376 |

OLIGOCENE FOSSILS
(-23,000,000 to -38,000,000 Years)

- | | |
|---------------|--|
| 1 = 29.6 Days | Sacate-Gaviota Formation
California |
| 1 = 29.5 Days | Sacate-Gaviota Formation
California |
| 2 = 29.2 Days | YPM-IP-28482 |
| 2 = 29.6 Days | YPM-IP-26377 |

Eocene Fossils

(-38,000,000 to -54,000,000 Years)

1 = 29.7 Days	Lutetian , Morigny France
2 = 29.6 Days	YPM-IP-26377
2 = 29.9 Days	YPM-IP-28496
2 = 30.0 Days	YPM-IP-26380
2 = 29.4 Days	YPM-IP-28480
2 = 29.6 Days	YPM-IP-28485

Paleocene Fossils

(-54,000,000 to -65,000,000 Years)

1 = 29.7 Days	Meganos Sandstone California
2 = 30.0 Days	YPM-IP-26380

Cretaceous Fossils

(-65,000,000 to -146,000,000 Years)

1 = 29.7 Days	Ripley Formation Tennessee
1 = 29.6 Days	Ripley Formation Tennessee
1 = 29.8 Days	Ripley Formation Tennessee
1 = 29.8 Days	Cody Shale, Greybull Wyoming
2 = 29.7 Days	YPM-IP-26322
2 = 29.9 Days	YPM-IP-26801
2 = 29.7 Days	YPM-IP-26802
2 = 30.2 Days	YPM-IP-26381
2 = 30.0 Days	YPM-IP-26382
2 = 29.8 Days	YPM-IP-28497
2 = 29.6 Days	YPM-IP-11655

Jurassic Fossils

(-146,000,000 to -208,000,000 Years)

1 = 29.8 Days	Leamington, England
2 = 29.8 Days	YPM-IP-26803
2 = 29.8 Days	YPM-IP-26804
2 = 29.3 Days	YPM-IP-26805

Triassic Fossils

(-208,000,000 to -245,000,000 Years)

1 = 29.8 Days	Luning Formation Nevada
2 = 30.0 Days	YPM-IP-26803
2 = 29.4 Days	YPM-IP-26804
2 = 29.4 Days	YPM-IP-26805

Permian Fossils

(-245,000,000 to -286,000,000 Years)

Carboniferous Fossils

(-286,000,000 to -360,000,000 Years)

1 = 30.0 Days	Gramham Formation Texas
1 = 30.2 Days	Wayland Formation Texas
1 = 30.2 Days	Carboniferous Belgium
2 = 30.7 Days	YPM-IP-26383
2 = 30.0 Days	YPM-IP-26378
2 = 29.9 Days	YPM-IP-26384
2 = 30.2 Days	YPM-IP-26323
2 = 30.2 Days	YPM-IP-26323
2 = 30.3 Days	YPM-IP-26806
2 = 30.5 Days	YPM-IP-26807
2 = 30.2 Days	YPM-IP-28499

DEVONIAN FOSSILS

(-360,000,000 to -410,000,000 Years)

1 = 30.5 Days	Alpena Limestone Michigan
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*For additional information concerning fossil records, refer to '**Approximate Ancient Time Formula Based on Fossil Data**' (<http://www.cs.colorado.edu/~lindsay/creation/coral-clocks.txt>).*

Of some significance here is a fossil from the late Cretaceous Era (or from about 65 million years ago) is noted to reflect a synodic month of 29.65 +/- 0.18 days. This respective interpretation then reflects that the count of the synodic month may then may have been somewhere between 29.47 days and 29.83 days.

So it seems evident from the previous table that the definition of the lunar-month cycle has changed over the previous millions of years. Bivalves now living show a synodic month of 29.5 days, and fossil bivalves living many million years ago (those from the Carboniferous Era) show a synodic month of 30 days. The higher count of days in the ancient lunar month is then rather apparent in the older geologic eras (from the Cretaceous Age and older).

The fossil record then does indicate the Earth-Moon may have once been configured rather differently from the modern system. In essence, the fossils show that the synodic month of the very distant past did contain a higher number of days (more than 29.5 days).

However, the following table illustrates that the younger fossils tend to indicate an unchanged definition of the synodic month (and this throughout--at least--the prior 54

million years):

AVERAGE DAYS IN THE SYNODIC MONTH
(Later than the Paleocene Age)

PLEISTOCENE FOSSILS
(-11,000 to -1,800,000 Years)

10 fossil samples average 29.33 days.
(All younger samples average 29.3 days)

PLIOCENE FOSSILS
(-1,800,000 to -5,000,000 Years)

2 fossil samples average 29.65 days.
(All younger samples average 29.4 days)

MIOCENE FOSSILS
(-5,000,000 to -23,000,000 Years)

5 fossil samples average 29.54 days.
(All younger samples average 29.4 days)

OLIGOCENE FOSSILS
(-23,000,000 to -38,000,000 Years)

4 fossil samples average 29.475 days.
(All younger samples average 29.4 days)

EOCENE FOSSILS
(-38,000,000 to -54,000,000 Years)

6 fossil samples average 29.70 days.
(All younger samples average 29.5 days)

If the definition of the synodic month has remained unchanged for what could be up into the many millions of years then any indicated change in the synodic month may have occurred in a more distant geologic age.

The previously cited table of fossil records shows that old fossils--those older than the Eocene Age--generally have a higher count of days in each synodic month. (All 31 of the older fossil samples when averaged together show a synodic month of 30 days).

It is then beyond a time reach of many million years ago that a change in the definition of the synodic month is more clearly manifested.

The long-term duration of the current Earth-Moon configuration ultimately seems remarkable. Rather than irrationally winding down, each rotation of the Earth, and each period of the Moon, seems to be moving in conformance with a (functional) schedule that means something. For a more complete analysis exposing what appears to be intelligent design--refer to:

A Question About Design

APPENDIX A

EXCESS OF THE DURATION OF THE DAY TO 86400S AND ANGULAR VELOCITY OF THE EARTH'S ROTATION (SINCE 1623)

Borrowed from: International Earth Rotation Service (IERS)

This table gives mean annual values of the duration of the day D , which are available for the last four centuries. For the interval 1623-1955, the data are those provided by L.V. Morrison, Royal Greenwich Observatory, interpolated for the middle of the year. The mean solar time has been referred to the dynamical time scale derived from the time argument of the lunar ephemeris.

The duration of the day has been obtained:

- from 1623 to 1860, by derivative of cubic splines fitted on individual values of the difference between mean solar time and dynamical time (13 knots),
- from 1861 to 1955, by a 5-point quadratic convolute.

More information on the computation of the duration of the day is available in Stephenson and Morrison (1984), with an estimation of the accuracy of these evaluations.

From 1956 up to present, the duration of the day has been obtained from the BIH/IERS values of $UT1-TAI$; the table gives annual averages. At the level of precision of these values of the duration of the day, the unit of the dynamical time and the unit of TAI can be considered as having the same duration. Thus D is expressed in present SI units. The table gives also the values of the angular velocity of the Earth's rotation w derived from the listed values of D .

DATE	D	[[omega]]
(years)	(ms)	(prad/s)
-----	---	-----
1623.5	-11.	161.
1624.5	-11.	161.
1625.5	-10.	160.
1626.5	-10.	160.
1627.5	-9.	159.
1628.5	-9.	159.
1629.5	-8.	158.
1630.5	-8.	158.
1631.5	-8.	158.
1632.5	-7.	157.
1633.5	-7.	157.
1634.5	-7.	157.
1635.5	-6.	157.
1636.5	-6.	157.
1637.5	-6.	157.
1638.5	-5.	156.
1639.5	-5.	156.
1640.5	-5.	156.
1641.5	-4.	155.
1642.5	-4.	155.
1643.5	-4.	155.
1644.5	-4.	155.
1645.5	-4.	155.
1646.5	-3.	154.
1647.5	-3.	154.
1648.5	-3.	154.
1649.5	-3.	154.
1650.5	-3.	154.
1651.5	-3.	154.
1652.5	-3.	154.
1653.5	-3.	154.
1654.5	-3.	154.
1655.5	-3.	154.
1656.5	-3.	154.
1657.5	-3.	154.
1658.5	-3.	154.
1659.5	-3.	154.
1660.5	-3.	154.
1661.5	-3.	154.
1662.5	-3.	154.
1663.5	-3.	154.
1664.5	-3.	154.
1665.5	-3.	154.
1666.5	-3.	154.
1667.5	-3.	154.
1668.5	-3.	154.
1669.5	-3.	154.
1670.5	-3.	154.
1671.5	-3.	154.
1672.5	-3.	154.
1673.5	-3.	154.
1674.5	-3.	154.
1675.5	-3.	154.
1676.5	-3.	154.
1677.5	-3.	154.
1678.5	-3.	154.

1679.5	-2.	153.
1680.5	-2.	153.
1681.5	-2.	153.
1682.5	-2.	153.
1683.5	-2.	153.
1684.5	-2.	153.
1685.5	-2.	153.
1686.5	-1.	152.
1687.5	-1.	152.
1688.5	-1.	152.
1689.5	-1.	152.
1690.5	-1.	152.
1691.5	-1.	152.
1692.5	-1.	152.
1693.5	0.	151.
1694.5	0.	151.
1695.5	0.	151.
1696.5	0.	151.
1697.5	0.	151.
1698.5	0.	151.
1699.5	0.	151.
1700.5	0.1	151.4
1701.5	0.2	151.3
1702.5	0.2	151.3
1703.5	0.3	151.2
1704.5	0.3	151.2
1705.5	0.3	151.2
1706.5	0.3	151.2
1707.5	0.3	151.2
1708.5	0.4	151.1
1709.5	0.3	151.2
1710.5	0.3	151.2
1711.5	0.3	151.2
1712.5	0.3	151.2
1713.5	0.3	151.2
1714.5	0.3	151.2
1715.5	0.2	151.3
1716.5	0.2	151.3
1717.5	0.2	151.3
1718.5	0.2	151.3
1719.5	0.2	151.3
1720.5	0.2	151.3
1721.5	0.2	151.3
1722.5	0.2	151.3
1723.5	0.1	151.4
1724.5	0.1	151.4
1725.5	0.1	151.4
1726.5	0.1	151.4
1727.5	0.1	151.4
1728.5	0.2	151.3
1729.5	0.2	151.3
1730.5	0.2	151.3
1731.5	0.2	151.3
1732.5	0.2	151.3
1733.5	0.2	151.3
1734.5	0.2	151.3
1735.5	0.2	151.3
1736.5	0.3	151.2
1737.5	0.3	151.2
1738.5	0.3	151.2
1739.5	0.3	151.2
1740.5	0.3	151.2
1741.5	0.3	151.2
1742.5	0.3	151.2

1743.5	0.4	151.1
1744.5	0.4	151.1
1745.5	0.4	151.1
1746.5	0.4	151.1
1747.5	0.4	151.1
1748.5	0.4	151.1
1749.5	0.4	151.1
1750.5	0.4	151.1
1751.5	0.4	151.1
1752.5	0.4	151.1
1753.5	0.4	151.1
1754.5	0.4	151.1
1755.5	0.4	151.1
1756.5	0.4	151.1
1757.5	0.4	151.1
1758.5	0.4	151.1
1759.5	0.4	151.1
1760.5	0.4	151.1
1761.5	0.4	151.1
1762.5	0.3	151.2
1763.5	0.3	151.2
1764.5	0.3	151.2
1765.5	0.3	151.2
1766.5	0.3	151.2
1767.5	0.3	151.2
1768.5	0.3	151.2
1769.5	0.3	151.2
1770.5	0.3	151.2
1771.5	0.3	151.2
1772.5	0.2	151.3
1773.5	0.2	151.3
1774.5	0.2	151.3
1775.5	0.2	151.3
1776.5	0.2	151.3
1777.5	0.2	151.3
1778.5	0.2	151.3
1779.5	0.2	151.3
1780.5	0.2	151.3
1781.5	0.2	151.3
1782.5	0.1	151.4
1783.5	0.1	151.4
1784.5	0.1	151.4
1785.5	0.0	151.5
1786.5	0.0	151.5
1787.5	-0.1	151.6
1788.5	-0.2	151.6
1789.5	-0.3	151.7
1790.5	-0.5	151.9
1791.5	-0.6	152.0
1792.5	-0.7	152.1
1793.5	-0.9	152.2
1794.5	-0.9	152.2
1795.5	-1.0	152.3
1796.5	-1.0	152.3
1797.5	-1.0	152.3
1798.5	-1.0	152.3
1799.5	-1.0	152.3
1800.5	-0.87	152.20
1801.5	-0.75	152.10
1802.5	-0.61	151.98
1803.5	-0.46	151.86
1804.5	-0.34	151.75
1805.5	-0.23	151.66

1806.5	-0.14	151.59
1807.5	-0.06	151.52
1808.5	-0.01	151.48
1809.5	0.03	151.44
1810.5	0.05	151.42
1811.5	0.05	151.42
1812.5	0.04	151.43
1813.5	0.01	151.46
1814.5	-0.04	151.50
1815.5	-0.11	151.56
1816.5	-0.18	151.62
1817.5	-0.28	151.70
1818.5	-0.39	151.80
1819.5	-0.51	151.90
1820.5	-0.65	152.02
1821.5	-0.81	152.15
1822.5	-0.99	152.30
1823.5	-1.16	152.45
1824.5	-1.32	152.58
1825.5	-1.42	152.67
1826.5	-1.49	152.72
1827.5	-1.50	152.73
1828.5	-1.48	152.72
1829.5	-1.41	152.66
1830.5	-1.30	152.56
1831.5	-1.14	152.43
1832.5	-0.94	152.26
1833.5	-0.73	152.08
1834.5	-0.52	151.91
1835.5	-0.34	151.75
1836.5	-0.18	151.62
1837.5	-0.04	151.50
1838.5	0.09	151.39
1839.5	0.19	151.31
1840.5	0.27	151.24
1841.5	0.33	151.19
1842.5	0.37	151.15
1843.5	0.39	151.14
1844.5	0.40	151.13
1845.5	0.41	151.12
1846.5	0.41	151.12
1847.5	0.40	151.13
1848.5	0.39	151.14
1849.5	0.38	151.15
1850.5	0.36	151.16
1851.5	0.33	151.19
1852.5	0.30	151.21
1853.5	0.26	151.25
1854.5	0.23	151.27
1855.5	0.20	151.30
1856.5	0.17	151.32
1857.5	0.15	151.34
1858.5	0.11	151.37
1859.5	-0.02	151.48
1860.5	-0.34	151.75
1861.5	-0.81	152.15
1862.5	-1.19	152.47
1863.5	-1.35	152.61
1864.5	-1.61	152.83
1865.5	-2.13	153.26
1866.5	-2.76	153.80
1867.5	-2.89	153.91
1868.5	-2.60	153.66
1869.5	-2.59	153.65

1870.5	-2.51	153.59
1870.5	-2.51	153.59
1871.5	-2.59	153.65
1872.5	-2.55	153.62
1873.5	-2.10	153.24
1874.5	-2.03	153.18
1875.5	-1.77	152.96
1876.5	-1.37	152.62
1877.5	-1.24	152.51
1878.5	-0.90	152.23
1879.5	-0.49	151.88
1880.5	-0.23	151.66
1881.5	-0.06	151.52
1882.5	-0.15	151.59
1883.5	-0.33	151.75
1884.5	-0.24	151.67
1885.5	-0.15	151.59
1886.5	-0.05	151.51
1887.5	-0.04	151.50
1888.5	-0.18	151.62
1889.5	-0.25	151.68
1890.5	-0.48	151.87
1891.5	-0.58	151.96
1892.5	-0.42	151.82
1893.5	-0.13	151.58
1894.5	0.33	151.19
1895.5	0.86	150.74
1896.5	1.53	150.18
1897.5	2.16	149.64
1898.5	2.64	149.24
1899.5	3.00	148.94
1900.5	3.31	148.67
1901.5	3.60	148.43
1902.5	3.70	148.34
1903.5	3.69	148.35
1904.5	3.55	148.47
1905.5	3.40	148.60
1906.5	3.48	148.53
1907.5	3.57	148.45
1908.5	3.65	148.39
1909.5	3.71	148.34
1910.5	3.77	148.29
1911.5	3.86	148.21
1912.5	3.89	148.18
1913.5	3.62	148.41
1914.5	3.18	148.78
1915.5	2.92	149.00
1916.5	2.74	149.15
1917.5	2.35	149.48
1918.5	2.05	149.74
1919.5	1.76	149.98
1920.5	1.48	150.22
1921.5	1.51	150.19
1922.5	1.28	150.39
1923.5	0.98	150.64
1924.5	0.93	150.68
1925.5	0.81	150.78
1926.5	0.56	150.99
1927.5	0.18	151.32
1928.5	-0.22	151.65
1929.5	-0.35	151.76
1930.5	-0.19	151.63
1931.5	-0.10	151.55
1932.5	-0.07	151.53

1933.5	-0.06	151.52
1934.5	-0.08	151.53
1935.5	0.00	151.47
1936.5	0.08	151.40
1937.5	0.22	151.28
1938.5	0.47	151.07
1939.5	0.78	150.81
1940.5	1.09	150.55
1941.5	1.25	150.41
1942.5	1.31	150.36
1943.5	1.35	150.33
1944.5	1.41	150.28
1945.5	1.41	150.28
1946.5	1.35	150.33
1947.5	1.30	150.37
1948.5	1.25	150.41
1949.5	1.20	150.45
1950.5	1.15	150.50
1951.5	1.10	150.54
1952.5	1.05	150.58
1953.5	0.99	150.63
1954.5	0.92	150.69
1955.5	0.86	150.74
1956.5	0.89	150.72
1957.5	1.34	150.34
1958.5	1.37	150.31
1959.5	1.31	150.36
1960.5	1.19	150.46
1961.5	1.09	150.55
1962.5	1.30	150.37
1963.5	1.54	150.17
1964.5	1.92	149.85
1965.5	2.21	149.60
1966.5	2.41	149.43
1967.5	2.37	149.47
1968.5	2.48	149.37
1969.5	2.67	149.21
1970.5	2.71	149.18
1971.5	2.90	149.02
1972.5	3.13	148.83
1973.5	3.05	148.89
1974.5	2.72	149.17
1975.5	2.69	149.20
1976.5	2.91	149.01
1977.5	2.77	149.13
1978.5	2.88	149.04
1979.5	2.61	149.26
1980.5	2.30	149.53
1981.5	2.16	149.64
1982.5	2.16	149.64
1983.5	2.28	149.54
1984.5	1.52	150.18
1985.5	1.45	150.24
1986.5	1.23	150.43
1987.5	1.36	150.32
1988.5	1.32	150.35
1989.5	1.53	150.18
1990.5	1.94	149.83
1991.5	2.04	149.75
1992.5	2.22	149.59
1993.5	2.37	149.47
1994.5	2.17	149.64
1995.5	2.31	149.52
1996.5	1.83	149.92

APPENDIX B

Universal Time and Delta-T

Atomic Time, with the unit of duration the Systeme International (SI) second defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133.

TAI is the International Atomic Time scale, a statistical timescale based on a large number of atomic clocks.

Universal Time (UT) is counted from 0 hours at midnight, with unit of duration the mean solar day, defined to be as uniform as possible despite variations in the rotation of the Earth.

UT0 is the rotational time of a particular place of observation. It is observed as the diurnal motion of stars or extraterrestrial radio sources.

UT1 is computed by correcting UT0 for the effect of polar motion on the longitude of the observing site. It varies from uniformity because of the irregularities in the Earth's rotation.

Coordinated Universal Time (UTC) differs from TAI by an integral number of seconds. UTC is kept within 0.9 seconds of UT1 by the introduction of one-second steps to UTC, the "leap second." To date these steps have always been positive.

Dynamical Time replaced ephemeris time as the independent argument in dynamical theories and ephemerides. Its unit of duration is based on the orbital motions of the Earth, Moon, and planets.

Terrestrial Time (TT), (or Terrestrial Dynamical Time, TDT), with unit of duration 86400 SI seconds on the geoid, is the independent argument of apparent geocentric ephemerides. $TDT = TAI + 32.184$ seconds.

Barycentric Dynamical Time (TDB), is the independent argument of ephemerides and dynamical theories that are referred to the solar system barycenter. TDB varies from

TT only by periodic variations.

Geocentric Coordinate Time (TCG) is a coordinate time having its spatial origin at the center of mass of the Earth. TCG differs from TT as: $TCG - TT = L_g \times (JD - 2443144.5) \times 86400$ seconds, with $L_g = 6.969291e-10$.

Barycentric Coordinate Time (TCB) is a coordinate time having its spatial origin at the solar system barycenter. TCB differs from TDB in rate. The two are related by: $TCB - TDB = iL_b \times (JD - 2443144.5) \times 86400$ seconds, with $L_b = 1.550505e-08$.

Delta-T = (TDT-UT).

APPENDIX C

Value of Delta T

Table and Text--as shown below--borrowed from

NASA Phase Catalog

As Earth rotates on its axis, tidal friction is imposed on it through the gravitational attraction with the Moon and, to a lesser extent, the Sun. This secular acceleration gradually transfers angular momentum from Earth to the Moon. As Earth loses energy and slows down, the Moon gains this energy and its orbital period and distance from Earth increase.

R. F. Stephenson and collaborators have produced a number of seminal works in the field of Earth's rotation over the past several millennia. In particular, they have identified hundreds of eclipse and occultation observations in early European, Middle Eastern and Chinese annals, manuscripts, canons and records. In spite of their relatively low precision, these data represent our only record to the value of delta-T during the past several millennia.

In Atlas of Historical Eclipse Maps East Asia 1500 BC - AD 1900, Stephenson and Houlden (1986) present two empirically derived expressions to describe the behavior of delta-T prior to telescopic records (pre-1600):

$$(1) \text{ prior to 948 AD}$$

$$\text{delta-T (seconds)} = 1830 - 405*t + 46.5*t^2$$

(t = centuries since 948 AD)

$$(2) \text{ 948 AD to 1600 AD}$$

$$\text{delta-T (seconds)} = 22.5*t^2$$

(t = centuries since 1850 AD)

More recently, Stephenson presents a new analysis of most if not all known solar and lunar eclipses that occurred during the period -700 to +1600 (Historical Eclipses and Earth's Rotation, 1997). The new analysis uses a spline to fit the observations.

The following table lists values of delta-T (seconds) derived from Stephenson and Houlden (1986), along with Stephenson (1997) for comparison.

Year	delta-T (1986)	delta-T (1997)
-2000	54181	-
-1900	51081	-
-1800	48073	-
-1700	45159	-
-1600	42338	-
-1500	39610	-
-1400	36975	-
-1300	34433	-
-1200	31984	-
-1100	29627	-
-1000	27364	-
-900	25194	-
-800	23117	-
-700	21133	-
-600	19242	-
-500	17444	16800
-400	15738	15300
-300	14126	14000
-200	12607	12800
-100	11181	11600
0	9848	10600
100	8608	9600
200	7461	8600
300	6406	7700
400	5445	6700
500	4577	5700
600	3802	4700
700	3120	3800
800	2531	3000
900	2035	2200
1000	1625	1600
1100	1265	1100
1200	950	750
1300	680	470
1400	455	300
1500	275	180
1600	140	110

(all values in seconds)

References for Delta-T

- Morrison, L.V. and Ward, C. G., "An analysis of the transits of Mercury: 1677-1973", Mon. Not. Roy. Astron. Soc., 173, 183-206, 1975.
- Stephenson F.R and Houlden M.A., Atlas of Historical Eclipse Maps: East Asia 1500 BC - AD 1900, Cambridge Univ.Press., 1986.
- Stephenson F.R., Historical Eclipses and Earth's Rotation , Cambridge Univ.Press, 1997.

APPENDIX D

Phase Rates for the Earth and Moon-- From Historic to Modern

The following data is predicated upon a catalog of previous phases of the Moon (refer to NASA tables).

LENGTH OF SYNODIC MONTH (4000 year time span)

Date of New Moon	Time	Julian Day
-----	-----	-----
Jan. 15, 2000 BE	02:18	990937.59583
Feb. 23, 2001 CE	08:22	2451963.84861

Total Years = 4000.15741
 Total Days = 1461026.25278
 Total Moons = 49475
 Average Month = 29.53060

For more information about time design, please select from among the following list of online literature"

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